Investigation of 100G (4x25G) NG-PON2 Upgrade using a Burst Mode Laser based on a Multi-Electrode Laser to enable 100 GHz Wavelength Grid

Vincent Houtsma[1], Doutje van Veen[1], Stefano Porto[1,2], Nagesh Basavanhally[1], Cris Bolle[1] and Harald Schmuck[3]

(1) Bell Labs, Nokia, 600-700 Mountain Avenue, Murray Hill, New Jersey, USA
(2) Tyndall National Institute, University College Cork, Cork, Ireland
(3) Bell Labs, Nokia, Lorenzstraβe 10, 70435 Stuttgart, Germany
vincent.houtsma@nokia-bell-labs.com

Abstract: Investigation of NG-PON2 upgrade to 25 Gb/s line-rate on a 100 GHz grid using a burst-mode transmitter based on a multi-electrode DFB. Compliance with NG-PON2 MSE requirements is shown.
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1. Introduction

In 2011 the Full-Service Access Network (FSAN) group introduced NG-PON2, a time- and dense wavelength-division multiplexed (TDWDM) PON using a line-rate of 10 Gbps per channel. As bandwidth demand keeps growing and optical spectrum is limited due to previous deployed PONs, upgrading the line-rate of NG-PON2 to 25 Gbps is of great interest to operators. The biggest challenges when increasing the serial rate beyond 10G, are the reduction in optical power budget and decreased chromatic dispersion (CD) tolerance. The latter is especially true for NG-PON2, since it operates in the C and L-band. Higher order modulation schemes like electrical duobinary (EDB) and PAM-4 can be applied to increase dispersion tolerance [1].

The other big challenge for upgrading NG-PON2 to 25G line-rate on a dense WDM grid is the optical spectral excursion of the burst mode (BM) ONU transmitter during a burst. The ITU specified that the Maximum Spectral Excursion (MSE) must not exceed ±20 GHz at -15 dB for a 100 GHz grid [2], which includes the modulated spectral width of the laser + the wavelength drift + the tuning error. A BM laser will have a substantial wavelength drift when turned on and off resulting in a penalty due to the signal drifting out of the channel into the neighboring channel(s). The tuning error is mostly due to thermal wavelength shifts because of varying burst lengths. Since it is not feasible to re-tune the BM laser between consecutive bursts this must be considered as well. And finally, higher bit-rate also results in a wider modulated spectrum.

In this paper, we propose to upgrade NG-PON2 to 25G line-rate using a novel very wavelength stable burst mode multi-electrode laser (MEL) [3]. We successfully validated the BM MEL transmitter against the stringent NG-PON2 requirements for a 100 GHz grid [2] and studied the effect of burst related wavelength drift on neighboring channels which has not been studied before in detail yet. A 100 GHz grid allows for thermal tuning over 4 channels, enabling an upgrade to 100G (4x25G). In previous work on λ-stable BM lasers [4,5] only relative wavelength drift (no detuning error) was measured for the different burst lengths and filters wider than specified in [2] were used.

2. Multi-electrode laser structure

Fig. 1 shows the setup used as well as a photo of the MEL laser. The MEL was fabricated in a standard InP DFB laser process by Fraunhofer HHI. It is a regular DFB laser, except that the top electrode is split into two halves.

Originally a MEL was used as a fast-tunable laser [6], but we invented [3] a way to operate a MEL as a very λ-stable BM laser. Keeping its temperature profile relative uniform by switching the driving currents I_1 (E1) and I_2 (E2) such that the sum of both currents is close to constant. In our experiments, we burst current I_2 from 0 to 10 mA, while current I_1 stays constant at 40 mA (so I_1+I_2 only varies 10 mA between on/off) allowing use of a regular burst mode laser driver. For example, a suppression of ~60 dB at the lasing wavelength is obtained between the on and off state at I_{MEL}=50mA, which is at +2 dBm output power.

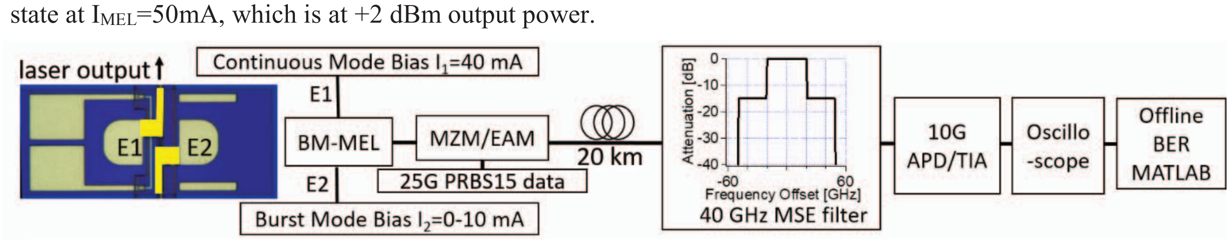

Fig. 1: Measurement setup using MEL (photo of structure inset) and a 40 GHz MSE filter (spectral shape inset).

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3. Wavelength drift measurements

We measured the wavelength drift of the MEL by means of heterodyne beating. The BM laser is mixed with a stable narrow linewidth external cavity laser (ECL) which is used as the reference frequency. Mixing results in a beating signal with frequency equal to the drift of the MEL relative to the ECL. A Hilbert transform is used to extract the frequency of the beating signal. For comparison, we first measured wavelength drift of the MEL with the electrodes E1 and E2 connected (BM=0 to 50 mA) to emulate a conventional single electrode laser. Three extreme BM patterns (1μs on/124μs off, 62.5μs on/62.5μs off, 124μs on/1μs off) were used to capture all burst length cases. From left side of Fig 2 it can be noted that the absolute wavelength drift (including detuning error) is as large as ±100 GHz for the emulated single electrode BM laser, which is similar as expected for a conventional BM DFB.

A semi-log scale is used to clearly show the 'fast' wavelength drift at the beginning of the burst which first drifts towards the lower wavelengths (blue shift due to carrier dynamics) and can be as large as +20 GHz, before drifting -70 GHz towards higher wavelengths (red shift) when thermal self-heating starts to set in. The right side of Fig. 2 shows the drift of the new MEL BM laser with the electrodes controlled separately. It can be observed that in this case the absolute frequency drift (including detuning error) stays within ±9 GHz for all the different BM patterns and the 'fast' wavelength drift at the beginning of the burst is minimized.

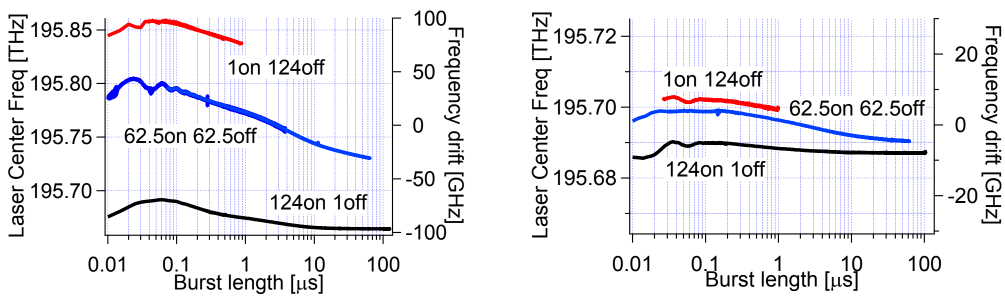

Fig. 2: Left: Measured frequency and drift for the various BM patterns of the emulated conventional DFB. Right: Measured frequency and drift for the various BM patterns of the multi-electrode laser (MEL)

4. In channel system measurements

The performance of the MEL was evaluated by measuring the bit-error rate (BER) in the channel itself using a fixed 40 GHz filter as shown in Fig 1, created using a Finisar Waveshaper, to represent the maximum spectral excursion (MSE) requirement for 100 GHz grid [2]. The left side of Fig 3 shows the BER performance of the MEL in the channel itself. 25G NRZ was transmitted and EDB detection was used in continuous mode (CM) as well as burst mode (BM) operation with 10G APD based receiver.

The BER was calculated offline on a PRBS15 block basis. A receiver sensitivity of -26 dBm at 25G (BER=10^{-3}) is measured using a Mach Zehnder Modulator (MZM). 10G BM NRZ is shown as a reference. No significant penalty was observed between CM and BM indicating the MEL stays within the 40 GHz filter during BM operation. It can be observed from Fig 3 (left side) that 20 km transmission in the C-band (λ~1532 nm) introduces only a small penalty (0.5 dB) compared to back-to-back (b2b) when using EDB detection at the receiver. For the downstream, we expect about 2dB dispersion penalty, based on higher CD in the L band (λ=1596-1602 nm). The modulated width of the spectrum at 15 dB down from the peak was measured to be ± 9 GHz. This means that the total MSE of our MEL including wavelength drift and BM detuning error is ± 18 GHz meeting the ITU requirement of ± 20 GHz for MSE as was also validated experimentally. Additional improvement is expected from the simplified scheme we applied when the MEL BM bias scheme is further optimized.

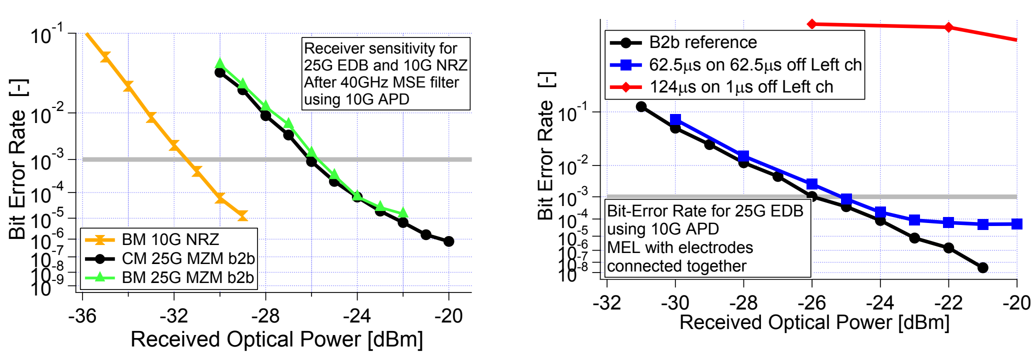

Fig. 3: Left: In channel BER performance of MEL using fixed 40 GHz MSE bandpass filter at receiver (see Fig 1). Right: Adjacent channel BER performance of MEL with electrodes connected (regular DFB).

5. Adjacent channel system measurements

BM drift can greatly affect the BER of neighboring channels, while only a small power penalty is observed in the channel itself, based on its ‘average’ BER measurement. We investigated the effect of drift related crosstalk by measuring the BER of the neighboring left and right channel while bursting the MEL laser with data in the center channel. For this a rectangular 100 GHz grid (created using the Finisar Waveshaper) is applied since it is the worst case for crosstalk in adjacent channels because the crosstalk to the adjacent channels is not attenuated for this case.

The received power of the BM MEL laser was fixed at -15 dBm, meaning a loud-soft ratio of 10 dB at -25 dBm (BER~10^{-3}) of received power was obtained. For a system implementation, this translates into > 25 dB loud/soft ratio when using a Gaussian shaped filter which will attenuate the crosstalk to its neighboring channels by at least another 15 dB due to its shape, meeting the worst case loud/soft requirement [2]. First the reference b2b BER of a 25G EDB continuous mode signal in the adjacent channel, with the MEL turned off in the center channel was measured as depicted in right side of Fig 3. Next the MEL was operated as a regular DFB with the electrodes connected using one of the three BM patterns and the BER of the right and left channel was measured again. It can be seen from right side of Fig 3 that for the 124μs on/1μs off case the left channel BER is very high because the wavelength of the BM laser shifted completely into the left channel. For the 62.5μs on/62.5μs off case only a small penalty is observed in the left channel. However, if we now plot the BER at -23 dBm as function of the number of PRBS15 blocks of the signal it can be observed from left side of Fig 4 that there is a large peak in the BER at block 62 due to the BM laser drifting into the channel for a short time. Although the ‘average’ BER ($7\cdot10^{-5}$) is still below FEC threshold for -23 dBm the data at block 62 is not correctable by FEC (1 PRBS15 block~1.3 μs) leading to transmission failure. The right side of Fig 4 shows the BER measurements of both adjacent channels bursting the MEL in the center channel with the electrodes controlled individually. In this case no degradation of the BER is observed in both adjacent channels for the different burst mode patterns while using a rectangular 100 GHz filter.

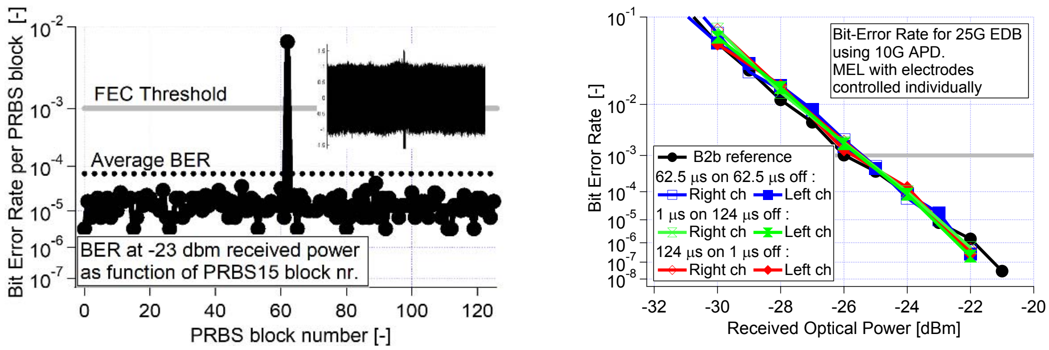

Fig. 4: Left: Left channel BER at -23 dBm as function of PRBS15 block number (measured data at block 62 inset). Right: Adjacent channel BER performance of MEL with electrodes controlled individually.

6. Conclusions and Discussion

We proposed a 25G line rate NG-PON2 upgrade using a novel very wavelength stable multi-electrode burst mode laser which meets the stringent MSE and maximum loud/soft burst power requirements for a 100 GHz grid. A record 10X reduction of BM wavelength drift + detuning error was observed with the MEL for the different burst lengths. 100 GHz grid also allows for thermal tuning of the MEL over 4 channels enabling a low-cost NG-PON2 upgrade to 100G (4x25G).

7. Acknowledgements

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8. References

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